Decontamination and Clearance of U.S. Army Chemical Agent Disposal Facilities

Environmental Public Health Readiness Branch

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Executive Summary

This experience is valuable because the closure of the CDFs provided unique examples of large-scale clean up due to chemical agent contamination. The major phases of the closure process were planning, decommissioning and decontamination, clearance, and post-clearance.

During the planning phase, potentially contaminated areas were identified. After identification of these areas, risk assessments were developed along with plans and procedures for decommissioning, decontamination, and verification of decontamination.

Decommissioning activities included de-energizing equipment and performing gross decontamination. After gross decontamination, equipment and items were removed that could not be decontaminated efficiently or effectively. Remediation of spaces where chemical agent could be trapped was critical to decontamination. Without identification and remediation of these spaces, residual agent contamination could remain despite the rigor of decontamination efforts.

For clearance after complete decontamination of a facility, unventilated air monitoring testing was used to determine the presence of any residual low-level chemical agent vapor emissions. To conduct unventilated air monitoring testing of an area, the area was sealed and isolated from a facility's ventilation system. This testing was performed on a room by room or area basis rather than by testing an entire facility.

For post-clearance once all of a facility's unventilated monitoring tests were completed, a formal decision process was used to determine whether the process was successful. Once deemed successful, engineering controls for agent hazards were no longer required and the facility ventilation system could be shut down. The buildings were opened to the atmosphere and prepared for demolition.

Introduction

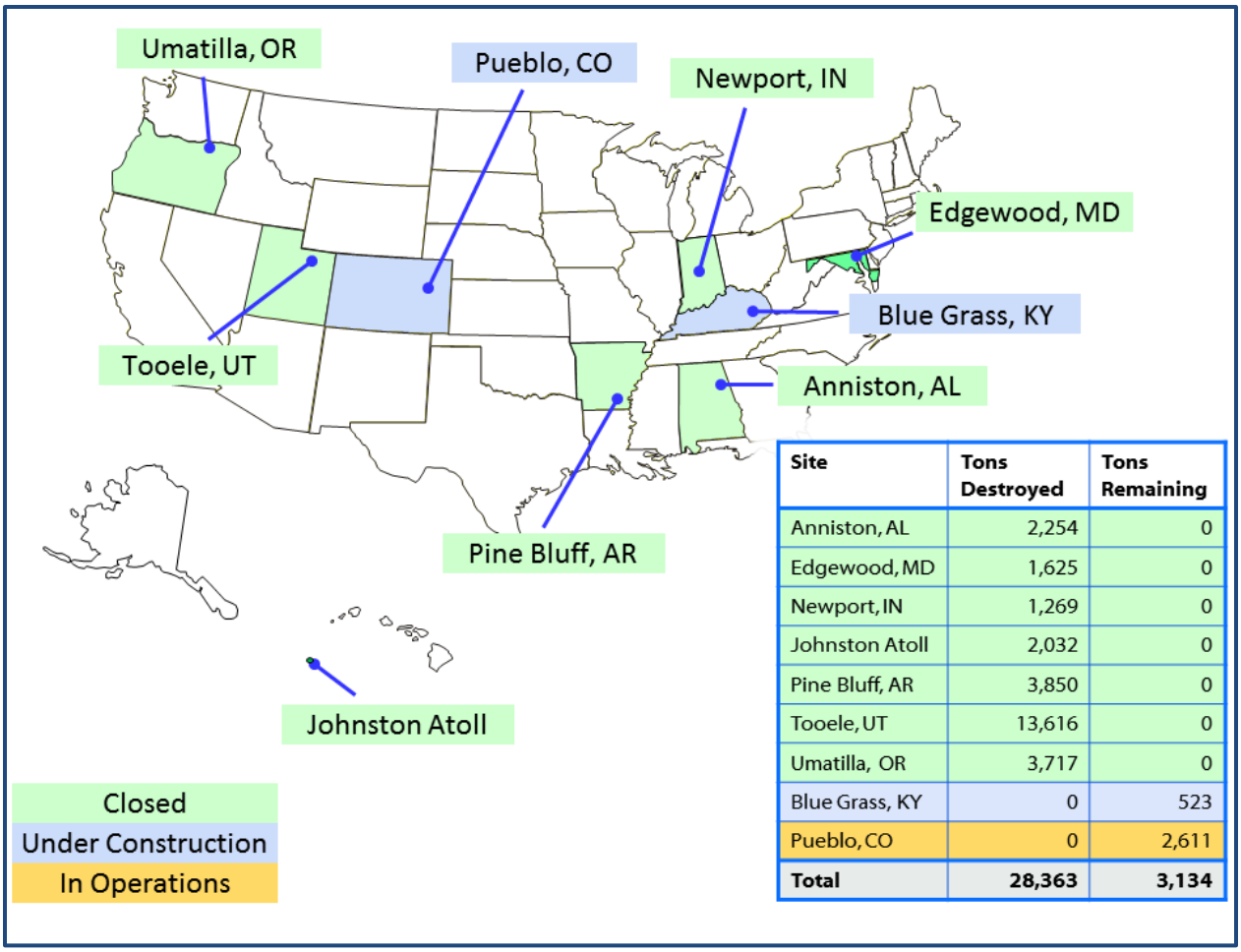
The United States began stockpiling chemical weapons during World War I. Eventually, these weapons were stored at eight sites within the continental 48 states and at one location approximately 800 miles southwest of Hawaii and included approximately 31,497 tons of chemical warfare agents (U.S. Army Chemical Materials Agency 2007). These agents primarily included the vesicant sulfur mustard and nerve agents sarin and VX configured as projectiles, mortars, bombs, mines, and bulk containers (Figures 1 and 2).

Figure 1. Stored Chemical Agent Projectiles (photo provided by the U.S. Army Chemical Materials Activity)

Figure 2. Stored Bulk Containers of Chemical Agent (photo provided by the U.S. Army Chemical Materials Activity)

As the stockpiles began to age and safe storage became more difficult, it became clear that these weapons would require destruction. While a program for disposal was being developed, the United States and other countries signed the Chemical Weapons Convention (Organisation for the Prohibition of Chemical Weapons no date). This treaty required signatories to destroy existing chemical warfare agent weapons stockpiles, refrain from manufacturing new chemical warfare agents, and work toward the peaceful use of chemistry.

To destroy the stockpiled weapons, disposal facilities were built adjacent to the storage areas. The U.S. Department of Defense (DOD) has destroyed all of the stored chemical weapons at seven of the nine storage sites—over 28,360 tons of chemical agent equaling more than 90% of the stockpile (Figure 3).



Site	Tons Destroyed	Tons Remaining
Anniston, AL	2,254	0
Edgewood, MD	1,625	0
Newport, IN	1,269	0
Johnston Atoll	2,032	0
Pine Bluff, AR	3,850	0
Tooele, UT	13,616	0
Umatilla, OR	3,717	0
Blue Grass, KY	0	523
Pueblo, CO	0	2,611
Total	**28,363**	**3,134**

Figure 3. Locations and Status of Chemical Agent Disposal Facilities

With chemical agent destruction completed, these facilities needed to be decontaminated and closed in accordance with their permits and applicable regulations.

This paper documents the methods used to decontaminate and verify successful decontamination in closing DOD chemical agent disposal facilities (CDFs). This experience is valuable because the closure of the CDFs provided unique examples of large-scale clean up due to chemical agent contamination. This paper addresses the following aspects of the decontamination and verification process:

- Type and extent of contamination.
- Evaluation of hazards (e.g. respiratory, dermal).
- Future use of facility.
- Decontamination methods.
- Verification screening.
- Final verification of decontamination.

CDC's Role in the Disposal of Chemical Weapons

Title 50, US Code, Section 1512 directs DOD to provide the U.S. Department of Health and Human Services (HHS) with details about DOD activities related to the testing, disposal, or transportation of lethal chemical warfare agents. HHS reviews details of the proposed activity for implications to public health and safety and recommends precautionary measures, if necessary, to DOD.

HHS delegated this responsibility to the CDC National Center for Environmental Health. After considering the potential for impacts to public health and safety during closure activities, DOD and CDC agreed that CDC would continue its role through the decontamination of a facility and disposition of contaminated materials.

CDF Closure Process

The overall strategy for the closure process was to successively reduce risk while fulfilling the requirements of a CDF's environmental permit. During this process, hazards were assessed to determine safety and environmental risks to define appropriate methodologies and controls. Given the highly toxic nature of the chemical weapons and the complexity of the facilities used to dispose of these weapons, closure of CDFs was a multi-staged process. Figure 4 summarizes this process for the CDFs (Program Manager for Chemical Stockpile Elimination 2008, URS 2008).

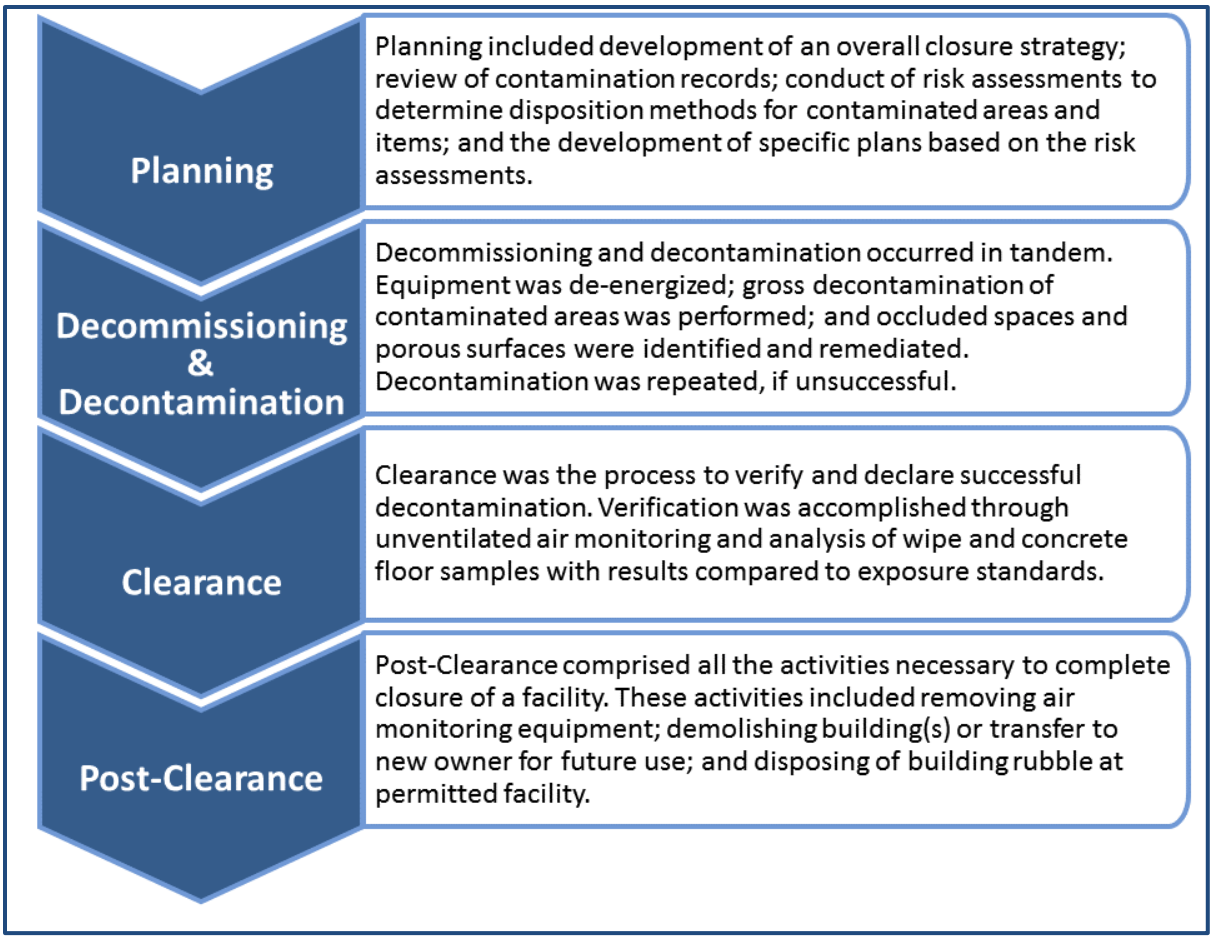


Figure 4. Overall Chemical Agent Disposal Facility Closure Process

Planning

At the CDFs, planning for closure began at least a year before destruction operations were completed. Planning activities (Washington Demilitarization Company 2012a) included

- Developing a closure strategy specific to the facility.
- Reviewing facility records to identify areas that had been potentially contaminated during operations.
- Developing an integrated, linked schedule so that activities occurred in the correct order and resources could be allocated to the planned activities.
- Preparing environmental permits.
- Conducting risk assessments to determine appropriate disposition of items, equipment, materials, buildings, and waste.
- Developing decommissioning, decontamination, and verification plans and procedures based on the risk assessments.
- Initiating closure-specific contracts and purchase orders.
- Developing and implementing a closure training program for employees.

The CDFs developed a strategy to explain the overall approach to closure (URS EG&G Technical Services 2008). It included a preliminary schedule tentatively identifying durations and expected timeframe for completion of significant closure activities as well as information about expected future use scenarios. From this high-level plan, more-detailed plans and assessments were developed for the different aspects of the closure process. The closure strategy addressed the following:

- Project management for coordination among various activities.
- Decommissioning and removal of equipment to facilitate decontamination and disposal.
- Decontamination of equipment, items, and structures.
- Demolition of buildings.
- Regulatory requirements of the facility (including permit modifications).
- Major milestones of closure process.
- Personnel transition.
- Records management.
- Property disposition.
- Contracting for supplies, equipment, demolition, and other skills or services.

Records Review and Risk Assessments

Because the facilities were designed to disassemble and destroy chemical agent, some areas of the CDFs were expected to become contaminated during the course of operations. With this expectation—and the requirements related to environmental permitting and facility closure—each facility maintained records of agent vapor and liquid spills during facility operation. These records included operator logs, spill reports, air monitoring data reports, operational condition reports, and incident investigation reports. At the closed sites, personnel were interviewed to confirm that potential contamination was not overlooked.

As part of the risk assessment process, levels of contamination were classified according to three guidelines (Program Manager for Chemical Stockpile Elimination 2008):

1. Contaminated: Exposed to liquid chemical agent, agent aerosols, or agent vapors with a concentration over the Immediately Dangerous to Life or Health level.
2. Clean after assessment: Never in contact with liquid agent, agent aerosols, or agent vapors with a concentration over the Immediately Dangerous to Life or Health level ***and*** has undergone a risk assessment that considered environmental conditions at the time of exposure.
3. Clean: Never in contact with liquid agent, agent aerosol environment, or condensing vapors AND never exceeded an agent Vapor Screening Level (generally the concentration associated with the Short-Term Exposure Limit).

In addition to the contamination history of a building or area, the risk assessments also considered future use of the areas. Figure 5 is a generic CDF site map showing the future use of each building and indicating conceptual levels of contamination in each area.

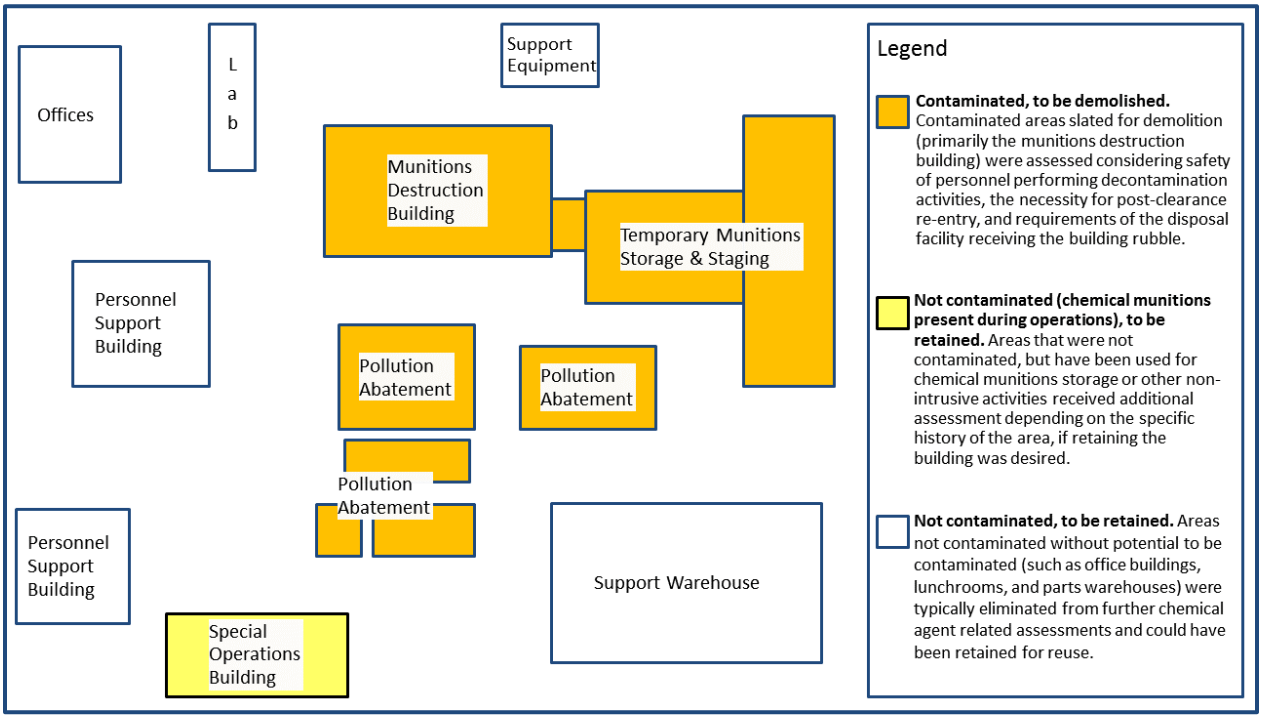


Figure 5. Generic Chemical Agent Disposal Facility Site Map

In addition to a building's or area's contamination history and future use, other considerations also influenced planning for decontamination and decommissioning (URS EG&G Technical Services 2008). These considerations included the following:

- Identification of any areas with significant contamination to reduce or eliminate potential for release of and exposure to hazardous constituents as early as possible during the closure process.
- Reevaluation of exposure risk to workers to determine the appropriate level of personal protective equipment (PPE) as contamination levels were reduced. Reduction of the exposure risk may also allow for revision of administrative and engineering controls.
- The cost/benefit of equipment salvage, material recycling, disposal options, decontamination methods, and time considerations.
- Reduction/minimization in the volume of waste requiring disposal in a permitted facility.

Through the risk assessment process, the Army established that buildings where weapons were disassembled and their chemical and energetics components destroyed should be decommissioned, decontaminated, and demolished with only the concrete pad remaining.

Building debris from demolition was transported to a permitted hazardous waste treatment storage and disposal facility for disposal.

Buildings with little to no possibility of having been contaminated by chemical agent were evaluated and managed according to any potential risk identified. Depending on the levels of contamination during operations, structures used to store munitions or chemical agent contaminated waste could be reused after decontamination and verification that acceptable residual contamination levels were reached. Verification standards for areas that would be reoccupied were more stringent than standards for areas where chemical agent destruction occurred. Buildings and structures that could not have been contaminated during agent operations, such as maintenance warehouses or cafeterias, might be reused without decontamination and verification.

The disposition of waste generated during the closure process was also determined through risk assessments. Waste with low levels of residual of chemical agent after decontamination was sent offsite to a permitted facility where it was disposed of by approved methods such as incineration or landfill. To minimize risks during shipment, delivery, and disposal, a risk assessment (U.S. Army Chemical Materials Agency 2008) was conducted to identify potential safety issues. Using this risk assessment as the basis, the Army developed policies and procedures to address any risks during transportation and disposal. CDC reviewed and provided recommendations to the policies and procedures to ensure protection of public and worker health and safety.

Plan Development

As the contamination history and associated risk assessments were completed, planning for facility decommissioning, decontamination, decontamination verification, demolition, and closure was conducted. Below are the principal plans that supported this process (Program Manager for Chemical Stockpile Elimination 2008):

1. The *Resource Conservation and Recovery Act (RCRA) Closure Plan* (where required) explained the technical and management information on the overall execution of closure activities required to comply with the RCRA environmental permit.

2. The *Closure Decommissioning Plan* explained the major tasks, methods, and activities required for closure of the facility. It included information about how detailed planning and execution was to occur, engineering controls required, and waste disposal.

3. The *Facility and Equipment Decontamination Plan* (Washington Demilitarization Company 2012b) outlined decontaminants that can be used, as well as integration of the work control process, including design changes, lock/out tag out considerations, development of work orders, and the review process. This plan also defined levels of contamination, occluded space, clearance levels, and other significant concepts and established the following:

- Criteria for the use of headspace monitoring for preliminary clearance of individual items and equipment.
- Air and solids criteria for the clearance of buildings/areas to meet state, federal, and Army regulations.
- Clearance criteria for liquid and solid wastes to be disposed of offsite.
- General clearance approaches for headspace monitoring and clearance of the facility.
- The general process to survey the facility for agent contamination (including records to review, interviews, and visual inspection) and to identify disposition of potentially contaminated items.

4. The *In-Progress Decommissioning Sampling Plan* described the methodology and procedures used to collect and analyze samples from agent-exposed equipment, materials, and areas to verify decontamination. Generally, the focus of this plan was on sampling concrete chips from the wall and floors of contamination areas.

5. The *Chemical Agent Air Monitoring Plan* explained the chemical agent air monitoring put in place to determine PPE requirements for workers.

6. The *Sampling and Analysis Plan* provided details on the sampling procedures, locations, and laboratory analytical methods to fulfill the requirements and procedures to confirm the adequacy of decontamination in accordance with the RCRA Closure Plan.

7. The *Quality Assurance and Quality Control Plan* specified the laboratory and monitoring quality assurance and quality control requirements during the closure process.

Decommissioning and Decontamination

With disposal operations completed and as the individual closure plans were completed, efforts shifted to decommissioning and decontamination of the facilities. These activities generally occurred concurrently.

Decommissioning

Decommissioning activities included the following:

- De-energizing equipment.
- Removing on-site material and equipment when deemed too contaminated to leave in place or more efficient than decontaminating in place. Items removed were either processed through one of the facility's incinerators or decontaminated by some other method.
- Flushing chemical agent piping.
- Disposing of residual secondary waste from operations.

Figure 6 illustrates the process to assess, decontaminate, verify, and determine disposition of equipment, material, and areas in a flow diagram.

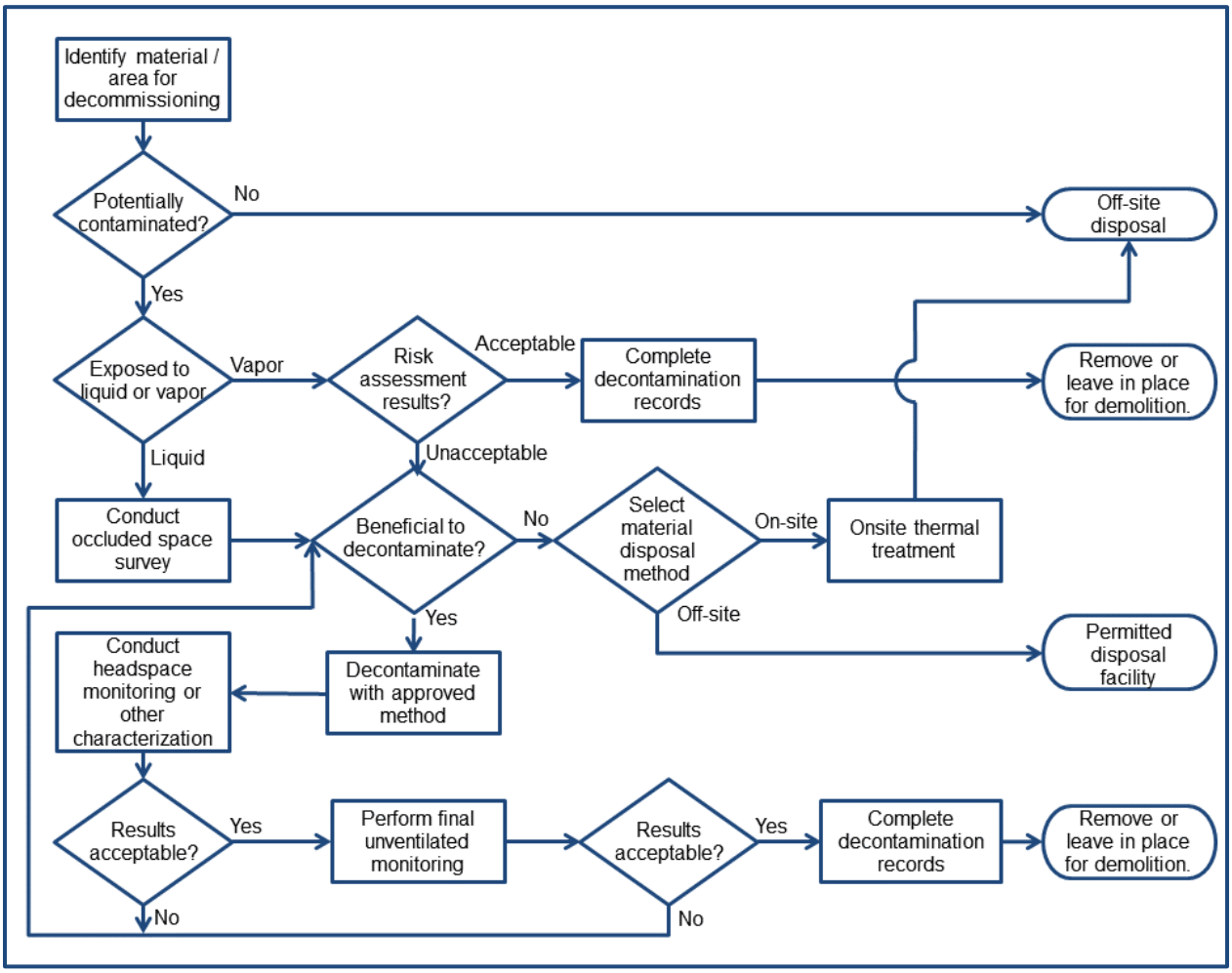


Figure 6. Generalized Decommissioning Process

Decontamination

In conjunction with decommissioning, initial (or gross) decontamination was performed to reduce high levels of contamination. Gross decontamination at CDFs was usually conducted using high-pressure hot water. For areas that were difficult to decontaminate, caustic or peroxide solution may have been used. Personnel removed equipment, materials, and tools that had been designated previously for removal. Generally, if items culd have been reused or recycled, they were further decontaminated to appropriate levels. If these items proved too difficult to decontaminate, they were thermally processed through the metal parts furnace or otherwise decontaminated for disposal at a permitted hazardous waste disposal facility.

The Army defined decontamination as

> *The process of decreasing the amount of chemical agent or industrial chemical on any person, object, or area by absorbing, neutralizing, destroying, ventilating, or removing chemical agent or industrial chemical.* (URS 2008)

Four primary decontamination techniques were used in the demilitarization program for equipment and facilities: chemical, mechanical, air wash, and thermal. Additional information regarding these decontamination techniques may be found in the appendix.

The process of decontamination consisted of several interconnecting activities. These are described in Figure 7 and in the paragraphs below.

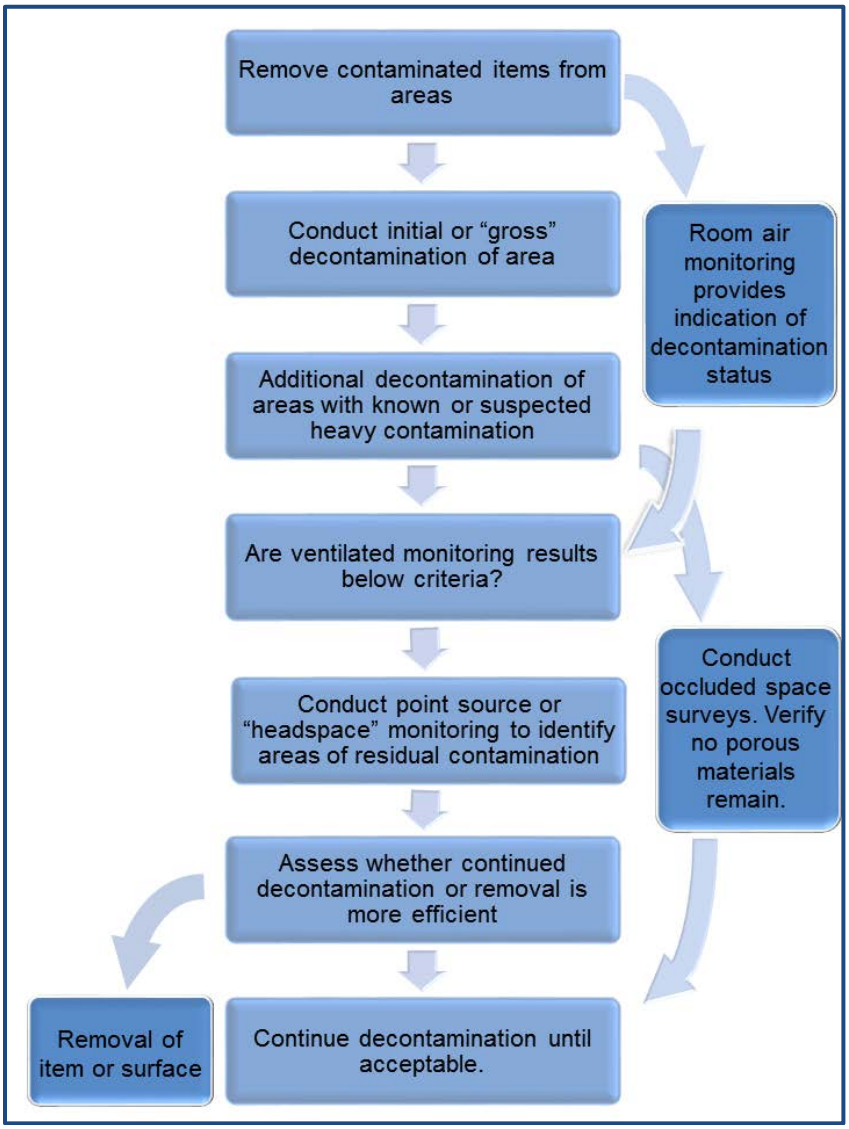


Figure 7. Decontamination Process at Chemical Agent Disposal Facilities

As decontamination progressed and agent readings from room monitors decreased, the levels of required PPE were continually reevaluated based on the task to be performed. However, even after entries into an area were typically being conducted in a downgraded[1] level of PPE, each task continued to be evaluated. If a task could have resulted in a higher hazard such as exposure to agent-contaminated liquids (for example, opening pipes or occluded spaces), the level of PPE would have been upgraded.

For areas of a CDF that had consistent agent air monitoring readings or areas with known or suspected liquid agent spills, headspace or point source monitoring was conducted to identify areas requiring additional decontamination (Washington Demilitarization Company 2012c). Headspace monitoring consists of enclosing the item or area with plastic sheeting or with another impermeable material, maintaining a temperature of 70°F or higher, providing time for agent vaporization within the enclosure, and monitoring agent air concentrations. Point source monitoring during this phase consisted of placing the end of a sampling line connected to a near real time monitoring device in close proximity to the area of suspected contamination. Typically, any positive response from the instrument was used as an indication that additional decontamination was necessary. Figure 8 shows an example of tenting at a CDF.

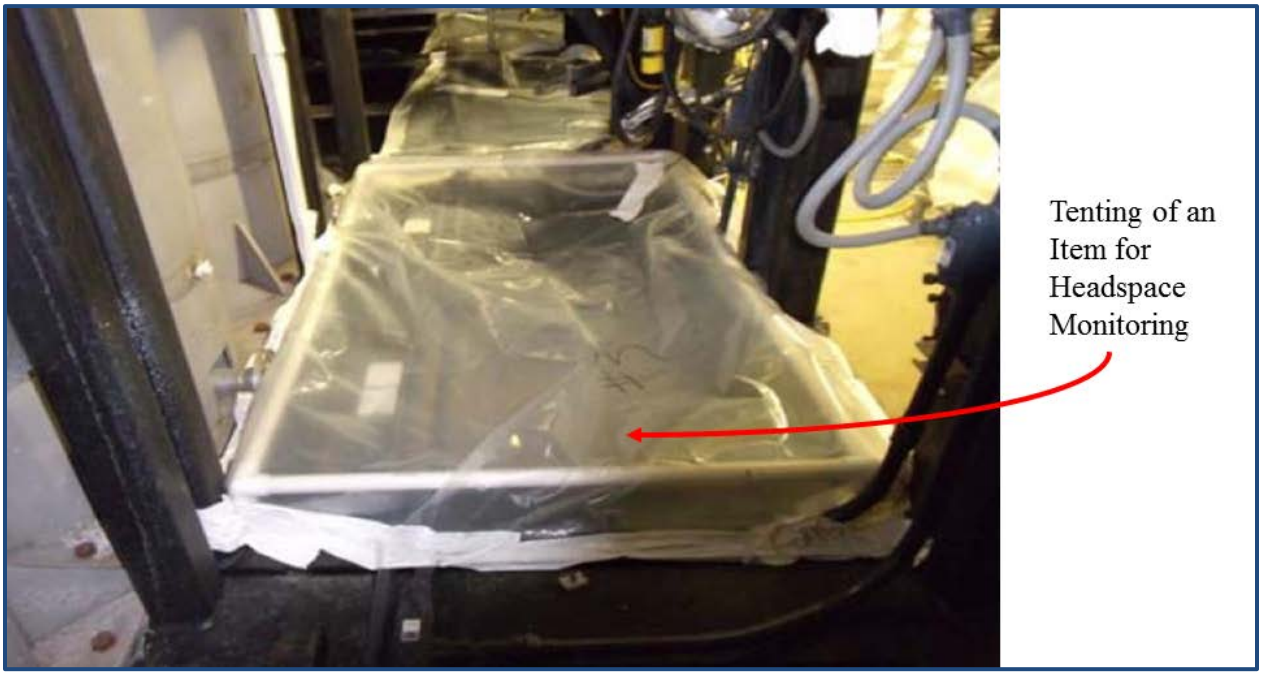


Figure 8. Example of Tenting an Item for Headspace Monitoring

[1] Downgrading the level of PPE appropriate to the level of contamination is necessary so that the risk of exposure to chemical agent is not overcome by the risks of wearing excessive PPE (e.g., heat stress, reduced ergonomic mobility, inhibited communication).

As isolated areas of contamination were found, additional mechanical and chemical decontamination were conducted. Equipment and items that had been left in place, yet could not have been decontaminated adequately, were typically removed and either processed through a facility's metal parts furnace or disposed of offsite. If the equipment or item at one of the closed CDFs was too large to remove, portable resistance electric heating was used to heat the item to 1,000°F for a minimum of 15 minutes. If an area of concrete could not have been decontaminated sufficiently, additional surface removal was conducted.

Generally, as residual contamination diminishes, point source monitoring of the floors and walls was conducted. Gridded maps of each room were developed. A portable air sampling wand was attached to a near real time monitor, and a worker passed the wand over a grid in a systematic fashion during the cycle time of the instrument. As with the point source monitoring described above, any positive response from the instrument would have typically resulted in additional decontamination of the area. However, areas where the walls had been contaminated and where the floor coating appeared degraded or breached, the surface layer of concrete was removed.

Identification and Remediation of Occluded Spaces

Addressing occluded spaces was considered critical to the integrity of the decontamination and verification process. Without identification and remediation of occluded spaces, there was a potential for continued residual agent contamination despite other rigorous decontamination and verification efforts.

While addressing occluded spaces at the CDFs, it was learned that liquid agent or other liquids contaminated with agent may had become trapped in small and seemingly sealed spaces. Examples of these spaces included the following:

- Screw and bolt holes that had come in contact with liquid or aerosolized agent while they had been removed during maintenance.
- Joints between supporting structures and floors or other surfaces.
- Spaces under floor mats, support plates, or other flat surfaces that covered a contaminated surface.
- Equipment and items with internal complex geometry and space behind O-rings and gaskets.

Any space where decontamination solution may not reach the agent, or where air monitoring may not have been able to detect any residual agent, was generally treated as an occluded space.

To minimize the potential that occluded spaces could have been missed, a systematic three-stage process was developed. These stages were identification, remediation, and final certification.

To oversee this process and to perform the final certification, each site established an *Occluded Space Survey Team*. The team typically consisted of personnel from relevant departments of a facility: closure, safety, laboratory, operations, maintenance, engineering, and quality assurance/quality control. The team identified potentially occluded spaces, facilitated remediation and verification planning, reviewed work records to verify that planned work had occurred, and maintained the documentation of the process.

Identification of occluded space included

- Reviewing the agent contamination history of the area to determine what may have come in contact with agent.
- Conducting a preliminary cost/benefit assessment on decontaminating items and equipment to leave in place for mass demolition versus removal and treatment. This was done on a case-by-case basis.
- Conducting an engineering review of relevant drawings to identify potentially occluded spaces not readily observable because of past changes to that area. This included any potential liquid or aerosol agent contamination or areas where the agent air monitoring concentrations exceeded the Immediately Dangerous to Life or Health values. If the area or item under consideration was known not to have come in contact with liquid, aerosol, or Immediately Dangerous to Life or Health vapor concentrations, it was not evaluated further.
- Inspecting the area visually. If a visual inspection identified any other potentially occluded spaces, they were added to the occluded space list.

Remediation of an occluded space consisted of opening the space, decontaminating the space, and placing an obstruction to ensure the space remained open.

In some instances, an occluded space team had determined that decontamination of the space would have been less efficient than removal and processing through the metal parts furnace or disposal at a permitted hazardous waste treatment, storage, and disposal facility. Similarly, if point source monitoring or tenting identified that decontamination efforts had not been successful, the equipment or item would have been removed for treatment and/or disposal. To verify successful decontamination of occluded spaces, point source or tenting would have been used, especially when the space was considered potentially problematic.

Verification of Occluded Space Remediation and Decontamination

To verify that potentially occluded spaces had been addressed, the occluded space survey team reviewed the documentation from identification, remediation, and verification for each occluded space. The team conducted visual inspections to verify that the field condition of the identified and remediated spaces correlated to the documentation and ensured that no potentially occluded spaces were overlooked.

Each part of the process was documented to capture potentially occluded spaces, results of evaluations of the spaces, any change in designation, decontamination and verification efforts, and a final report on the status of each identified potentially occluded space. These reports became part of the historical record for the facilities.

Documentation from occluded space surveys (Washington Demilitarization Company 2012d) included the following:

- Occluded space survey team personnel.
- Copy of facility assessment.
- Date of occluded space survey or occluded space remediation.
- Specific room, area, or equipment surveyed (with survey map).
- Specific identification of the occluded space (with photographs if possible).
- Specific location of the occluded space (with supporting drawings and pictures).
- Action required for remediation of the occluded space.
- Monitoring requirements (if any) after the occluded space had been remediated.
- Work orders accomplishing the remediation effort.
- Final signed-off certification form from key members of the occluded space survey team that the system or area was free of potentially occluded spaces.

A similar process was performed for areas that were difficult to decontaminate. Documentation related to the decontamination activities was reviewed to ensure that headspace or point source monitoring indicated reduction in contamination to acceptable levels.

Clearance

As discussed above, the primary objective in decontaminating the CDFs during closure was to reduce contamination to the point where a facility could be remotely demolished and disposed of in a permitted hazardous waste treatment, storage, and disposal facility. A secondary objective was to enable workers in appropriate PPE to enter decontaminated buildings without facility engineering controls after those buildings were cleared and before demolition so they could perform a limited number of finalizing tasks (URS EG&G Technical Services 2010).

After decontamination and preliminary verification of an area in the facility, an unventilated monitoring test would have been conducted to determine whether any residual significant low-level vapor emissions from floors, walls, or remaining equipment was present. To have been considered an unventilated test, airflow from the facility's heating, ventilation, and air conditioning must have been turned off and any openings to the area sealed. Isolating the area to be tested was important because it prevents dilution of emissions from any residual contamination.

Clearance levels for air monitoring were selected based on what was necessary to ensure workers at the site and at the offsite permitted treatment, storage, and disposal facility would not have been exposed to unacceptable levels of chemical agent. It was desired to use already

established program levels to help explain the clearance concepts to site personnel and stakeholders and to facilitate implementation of the unventilated monitoring test process using monitoring equipment, sampling and analysis methodologies, and agent vapor concentration levels already in place. In establishing the clearance levels, the focus was on determining whether the programmatic clearance levels already in place were sufficiently protective, rather than on developing new clearance levels based on the highest level of residual contamination that would still have been protective.

The level for passing an unventilated monitoring test was set to the vapor screening level (VSL), which was defined for this purpose as the concentration associated with the short-term exposure level without the time-weighted component (Table 1).

Table 1. Example of Plastic Sheeting Used to Seal Opening (left) and Smoke Testing of a Sealed Opening (right)

Agent	**Vapor Screening Level** (U.S. Army Chemical Materials Agency 2004)
Sulfur Mustard	0.003 mg/m^3
Sarin	0.0001 mg/m^3
VX	0.00001 mg/m^3

To verify that the VSL was adequately protective, the maximum potential off-gas rate was determined by calculating the rate that would have enabled a 1-VSL concentration after an 8-hour unventilated period. This off-gas rate was then used to model potential ventilated concentrations inside the building and potential concentrations downwind. Modeled concentrations were accepted if they did not exceed the concentrations associated with the worker population level (WPL) for locations within the installation boundaries and the general population limits for downwind locations where the public could be present.

Several sites used the VSL as the threshold acceptance criteria and set a goal of a lower concentration equal to the concentration associated with each agent's WPL. Generally, if the vapor concentration was less than the VSL and higher than the WPL, the test was considered successful, but as an added measure of protection, the facility conducted either additional decontamination to lower the vapor levels or instituted other precautions in the event personnel entry was required after the removal of engineering controls. Table 2 provides the concentrations associated with the WPL for each agent.

Table 2. Eight-Hour Worker Population Limit Concentrations

Agent	Worker Population Limit (U.S. Army Chemical Materials Agency 2004)
Sulfur Mustard	0.0004 mg/m^3
Sarin	0.00003 mg/m^3
VX	0.000001 mg/m^3

Clearance levels for concrete samples were generally set by the state environmental regulatory agencies through the facility permit. In most cases these levels were based on the U.S. Army military personnel drinking water standards in place at the time the facility permit was finalized. These levels are presented in Table 3 (URS EG&G Technical Services 2010).

Table 3. General CDF Concrete Clearance Levels

Agent	Clearance Level
Sulfur Mustard	200 ppb
Sarin	20 ppb
VX	20 ppb

As discussed above, unventilated monitoring tests were conducted only after a rigorous process of decommissioning and decontamination. The fundamental aspects to the success of this process were as follows:

- Identification of contaminated areas.
- Decontamination planning based on contamination history.
- Thorough decontamination.
- Preliminary targeted verification of decontamination and absence of free liquids.
- Occluded space survey and remediation.
- Use of other verification methods (concrete sampling).
- Structured review process to verify required activities were completed.
- Detailed documentation of each activity during the process.

Before conducting an unventilated monitoring test, a review was conducted to verify that each of these activities had been completed for each area that was to undergo an unventilated monitoring test. As these reviews were completed, areas were then prepared for testing. These preparations can be generalized into the following categories (Washington Demilitarization Company 2012e):

- Installation of equipment to monitor decontamination progress (circulation fans, heaters and temperature sensors, chemical agent monitors).
- Reconfiguration of the heating, ventilating, and air conditioning system so that isolation from other areas was possible.
- Physical isolation of the area.
- Placement of portable fans to minimize dead spaces and facilitate air mixing with a maintained temperature above 70°F throughout the area.

Figure 9 provides an example of fan placement for an unventilated monitoring test. With the isolation of the area to be tested from the heating, ventilation, and air conditioning system, small heaters were set up to maintain the required temperature and multiple temperature sensors were placed around the area to measure and record temperature during the unventilated monitoring test.

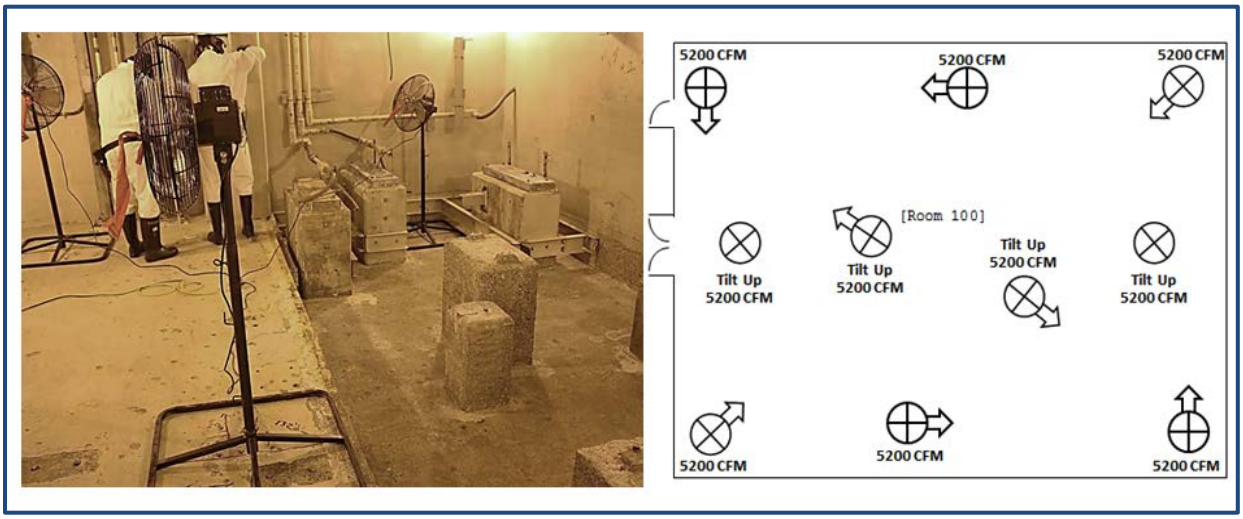


Figure 9. Example of Fan Placement for Air Circulation (left) and a Fan Placement Map (right)

CDFs only processed one type of chemical agent at a time, so the existing monitoring equipment at the end of operations was typically configured only for one agent. As a result, additional monitoring equipment was required to simultaneously monitor for agents sulfur mustard, sarin, and VX.

Most facilities used near real time monitors to verify the VSL requirement. Sorbent tubes were used to verify the WPL concentration goal and to confirm any chemical agent readings from the near real time instruments (U.S. Army Chemical Materials Agency 2004). Figure 10 shows an example of an agent sampling location.

Figure 10. Example of an Agent Sampling Location

The heating, ventilation, and air conditioning system was part of the facility engineering controls that included cascading ventilation that pulled air from the outside through progressively more contaminated areas. To isolate an area for the unventilated monitoring test, existing isolation dampers, fire dampers, and balance dampers were closed. In some instances, plywood panels and polyethylene plastic sheeting were used to adequately seal opening and penetrations. After sealing the areas, testing was performed to ensure there was no significant airflow. Figure 11 provides examples of the use of plastic sheeting and smoke testing of a sealed opening.

Figure 11. Example of Plastic Sheeting Used to Seal Opening (left) and Smoke Testing of a Sealed Opening (right)

Once decontamination and preparation for the unventilated monitoring tests was completed, each facility established a review process to ensure that all the required activities for each area to undergo an unventilated monitoring test had been performed satisfactorily. This process included an assessment of readiness conducted by a committee of senior managers from each department (e.g., operations, safety, environmental, maintenance, laboratory and monitoring, and quality).

After the committee reviewed the work packages and reports for each activity, the committee documented the successful completion of the prerequisite activities. The committee used a checklist to document the assessment. Activities on the checklist included the following:

- Documentation of any remaining equipment.
- Verification that
    - Loose debris was removed.
    - Headspace monitoring results were below or equal to 1-VSL.
    - Sample lines and mixing fans were placed properly.
    - The area was isolated from the heating, ventilation, and air conditioning system and adjoining rooms.
    - Temperature monitoring was in place and the area temperature was above 70°F.
    - Occluded spaces were remediated within the unventilated monitoring test area boundary.
- Results from
    - Monitoring quality assurance and control activities.
    - Any surface sampling of walls and floors.

Once the committee completed the assessment and declared an area ready, the actual unventilated monitoring test could begin. The checklist and supporting documentation were compiled in a report for each area undergoing an unventilated monitoring test.

Post Clearance

After each unventilated monitoring test at a facility was completed, the data were collected and reviewed for acceptability and a final report prepared. During this period, the area heating, ventilation, and air conditioning system was returned to pretest conditions and area entry requirements remained in place until final approval was granted.

After successful completion of all of a facility's unventilated monitoring tests, a formal decision process was used to determine whether the process succeeded. Once decontamination and verification were deemed successful, engineering controls for agent hazards were no longer required and the facility heating, ventilation, and air conditioning system was shut down. The buildings were opened to the atmosphere, and any remaining items that could be reused, reclaimed, or recycled were removed. Facility ventilation was replaced with natural ventilation and, if necessary, supplemented with other ventilation or administrative controls to protect

against chemical agent exposures over the WPL in accordance with the facility industrial hygiene plan.

After all equipment and wastes were removed, any remaining ventilation was discontinued and power to the building was disconnected. At this point the facility was turned over for mass demolition. During mass demolition, work was conducted remotely using mechanical demolition equipment to minimize the potential that personnel could come in contact with any residual agent contamination. Building debris was transported to permitted hazardous waste landfills for disposal (Washington Demilitarization Company 2012a).

Conclusion

To date, the U.S. Army has destroyed 90% of the nation's stockpile of chemical weapons at seven locations. After destruction of the stockpiles, each facility went through decommissioning, decontamination, verification that decontamination was successful, and demolition. Throughout the process, the Army developed approaches and methods to find and decontaminate chemical agent, characterize and mitigate hazards, verify decontamination, and conduct mass demolition of facilities while protecting worker safety and public health. Closure of these facilities represents one of the few examples of large-scale clean up and verification from chemical agent contamination.

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Appendix. Supplemental Information Regarding U.S. Army Decontamination Techniques during Closure of Chemical Agent Disposal Facilities

Chemical Decontamination

Surfactants. Surfactants in water combined with scrubbing or other mechanical action were useful to remove chemical agent from surfaces. Surfactants used included unscented Dawn, Simple Green, and Whistle.

Peroxide based solution. Clean Earth Technologies, LLC chemical decontamination solution (CET-CDS) has been used successfully as a decontaminant and as an indicator of remaining organic contamination on surfaces.

Bleach. Liquid bleach (NaOCl) and solid bleach ($Ca(OCl)_2$) were used for decontamination of chemical agent. The use of the solid form in water solution also provides an abrasive effect, which was believed to remove agent from surfaces mechanically.

Mechanical Decontamination

Scrubbing. Scrubbing with brushes was useful during the decontamination process, particularly when used along with a chemical decontamination solution. This technique was beneficial when chemical agent was partitioned into hydrophobic materials such as oils and grease.

Surface removal. Removing the surface layer of concrete, generally less than ½ inch, was used for areas where the special coating of the floor had been breached. Equipment used included Brokk scabbler and Nitrocision cleaning equipment.

Air Wash Decontamination

Air movement. Moving air over a surface to encourage vaporization or drying was generally used before headspace monitoring of items or areas.

Thermal Decontamination

Incineration. CDFs using incineration for destruction could process heavily contaminated items through the metal parts furnace used to treat munition bodies. Items processed through the furnace were heated to 1,000°F for a minimum of 15 minutes (Program Manager for Chemical Stockpile Elimination, 2008), thus destroying any chemical agent.

Resistance heating. Insulated electrical heaters were placed on the surface of items made of metal, such as ductwork, that were too large to remove or too difficult to decontaminate. Items were heated to a temperature of at least 1,000°F for 15 minutes. Thermocouples were used to monitor the temperature.